Frascati Physics Series Vol. XLVI (2007), pp. 000-000
HADRON07: XII Int. Conf. on Hadron Spectroscopy * Frascati, October 8-13, 2007
Parallel Session

Exotica possibility of new observations by BES

Ailin Zhang
Department of Physics, Shanghai University, Shanghai, 200444, China

Abstract

The employment of interpolating currents of existed studies of four-quark state and glueball with QCD sum rule approach is analyzed. In terms of suitable currents, the masses of the lowest lying scalar and pseudo-scalar glueball were determined. The masses of some tetraquark states and their first orbital excitations were obtained through a combination of the sum rule with the constituent quark model. Exotica possibility of the new observations by BES is discussed.

1 QCD sum rules and exotica

QCD is believed the right theory describing strong interactions, quark model is proved successful in describing normal hadron. However, the low energy behavior of QCD and the mechanism of quark confinement of hadron are not clear. The study of hadron properties with QCD is a great challenge. In history,

many models based on QCD were developed to study hadron. QCD (SVZ) sum rule [1] is such an effective nonperturbative method of relating fundamental parameters of QCD Lagrangian and vacuum to parameters of hadrons.

In sum rules method, to detect the properties of hadrons, some correlators are constructed from suitable interpolating currents (local operators). In one hand, the correlator is expanded in perturbative coefficients and condensates. In the other hand, the imaginary part of the correlator (spectral density) is expressed with the parameters of resonances. Through a dispersion relation, the parameters of QCD and vacuum are connected with the parameters of hadrons. To get reasonable conclusions on the properties of hadrons, it is very important to employ suitable currents.

In normal hadron case, the structure of meson and baryon is not so complex and sum rule works well. Exotic hadrons such as glueball, hybrid and multi-quark state have complex intrinsic structure, there are often different ways to employ interpolating currents. Furthermore, no exotic hadron has been confirmed such that the properties of exotic hadrons are not clear. Whether QCD sum rule works or not has not been proved. It should be careful to employ reasonable currents and to draw corresponding conclusions on exotic hadrons.

2 0^{++} and 0^{-+} glueballs

The existence of glueball was firstly mentioned by Fritzsch and Gell-Mann [2]. Glueball was studied in many models. In sum rules approach, the interpolating currents consist of gluons fields.

For 0^{++} glueball, the current was firstly employed by Novikov et al [3].,

$$j_s = \alpha_s G^a_{\mu\nu} G^a_{\mu\nu}, \tag{1}$$

where $m_\sigma = 700$ MeV was taken as that of the σ without computation.

Subsequently, the 0^{++} scalar glueball was studied with the same current in many literatures. In Narison's [4] work, $m = 1.5 \pm 0.2$ GeV was predicted. In the work of Huang's [5], $m = 1.7 \pm 0.2$ GeV was predicted with a reasonable moment. In the work of Harnett's [6], two glueballs were predicted with the heavier: $m = 1.4$ GeV and the lighter: $m \approx 1.0 - 1.25$ GeV, where the contribution of instanton was taken into account. In a most recent work by Forkel [7], with a comprehensive inclusion of the contribution of operator product expansion, $m = 1.25 \pm 0.2$ GeV was predicted.

For 0^{-+} glueball, the interpolating current was also firstly employed by Novikov et al [8].,

$$j_{ps} = \alpha_s G^a_{\mu\nu} \tilde{G}^a_{\mu\nu}. \tag{2}$$

In their computation, $m = 2 - 2.5$ GeV. This interpolating current was also employed to study pseudoscalar glueball in many other literatures. In Narison's [4] work, $m = 2.05 \pm 0.19$ GeV was predicted. With the higher-loop perturbative contributions and instantons taken into account, $m = 2.65 \pm 0.33$ GeV was predicted in the work of Zhang's [9]. In Forkel's work, the instanton and the topological charge screening effect were taken into account, and $m = 2.2 \pm 0.2$ GeV. It is widely believed that the mass of the 0^{-+} glueball is larger than that of the 0^{++} glueball.

In the constituent parton model, there are glueball with two gluons and glueball with three gluons. In sum rule method, in addition to the interpolating currents consisting of two gluons field, interpolating currents consisting of three gluons field have been employed. There is a large mass difference between the 0^{-+} and the 0^{++} glueball prediction. The difference may results from the rough calculations or the special features of the 0^{-+} glueball and the 0^{++} glueball. For the difficulty in the calculation of the OPE, present results on glueball masses are not definite and may be improved largely with more accurate computation.

Current consisting of three gluons field was firstly employed by Latorre et al. [10] to compute the mass of the 0^{++} scalar three gluons glueball

$$j_{s3g} = g^3 f_{abc} G^a_{\mu\nu} G^b_{\nu\rho} G^c_{\rho\mu}, \tag{3}$$

with $m_{s3g} = 3.1$ GeV.

Current consisting of three gluons field was recently employed by Hao et al. [11] to compute the mass of the 0^{-+} pseudoscalar three gluons glueball

$$j_{ps3g} = g^3 f_{abc} \tilde{G}^a_{\mu\nu} \tilde{G}^b_{\nu\rho} \tilde{G}^c_{\rho\mu}, \tag{4}$$

with $m_{ps3g} = 1.9 - 2.7$ GeV.

As well known, two gluons glueball may mix with three gluons glueball, and two gluons currents may mix with three gluons currents. Furthermore, this two kinds of currents couple to both kinds of glueballs. How to deal with these mixing effects is a great challenge in sum rule approach. Final conclusions on glueball are expected to depend heavily on these mixing effects.

3 0^{++} and 1^{--} tetraquark states

Four-quark state has been studied in MIT bag model [12], color junction model [13], potential model [14], effective Lagrangian method [15], relativistic quark model [16], QCD sum rules [17, 18, 19, 20, 21, 22] and many other methods [23]. More references could be found in Refs. [24] and therein.

Four-quark state consists of four quarks and anti-quarks. Their intrinsic quarks/anti-quarks may make different clusters (correlations) such as color, flavor, spin, *etc* [12, 22, 24]. According to the spacial extension of clusters, there are two different types of four-quark states: $(qq)(\bar{q}\bar{q})$ and $(q\bar{q})(q\bar{q})$. $(qq)(\bar{q}\bar{q})$ is often called tetraquark state or baryonium, which consists of diquark qq and anti-diquark $\bar{q}\bar{q}$. $(q\bar{q})(q\bar{q})$ includes the molecule state.

$(qq)(\bar{q}\bar{q})$ and $(q\bar{q})(q\bar{q})$ may mix with each other, and they may mix with normal meson $q\bar{q}$ (the ones mixed with $q\bar{q}$ are usually called crypto-exotic four-quark states). Therefore, the meson observed by experiment is a mixed one

$$|meson>=|q\bar{q}>+|(qq)(\bar{q}\bar{q})>+|(q\bar{q})(q\bar{q})>+\cdots. \tag{5}$$

Quark dynamics in four-quark state is still not clear, so intrinsic color, flavor configurations in four-quark state could not be distinguished except that some special observable is established. Unfortunately, no such an observable has been definitely set up.

To study four-quark state with sum rule, two kinds of interpolating currents, for example,$(q\bar{q})(q\bar{q})$ [17], $(q\bar{q})^2$, $(qq)(\bar{q}\bar{q})$ [18], $(cq)(\bar{q}\bar{q})$ [19], $(cu)(\bar{s}\bar{u})$ [20], $(ud)(\bar{s}\bar{s})$ [21], have been employed. All the calculations are in leading order.

Many conclusions on four-quark states have been drawn based on this two kinds currents. However, in view of the sum rule approach, there is no definite difference between this two kinds currents. The reason is that $(qq)(\bar{q}\bar{q})$ and $(q\bar{q})(q\bar{q})$ can be turned into each other after Fierz transformation [18, 22], and they will mix with each other under renormalization. Therefore, it is useful to remember that conclusions on the structure of four-quark state in constituent quark picture can not be drawn directly from the structure in current (operator) picture. Similarly, diquark concept is not meaningful in current picture [22]. In principle, there is no direct way to turn the current (operator) picture into the constituent quark picture.

To get a reasonable result on four-quark state, suitable mixed interpolating currents and mixture of hadrons should be taken into account, which is

Table 1: *Masses of some tetraquark states.*

	0^{++}	1^{-+}
$[qq][\bar{q}\bar{q}]$	~ 490 MeV	$\sim 490 + B'_q$ MeV
$[sq][\bar{q}\bar{q}]$	~ 610 MeV	$\sim 610 + B'_q$ MeV
$[sq][\bar{s}\bar{q}]$	~ 730 MeV	$\sim 730 + B'_s$ MeV

also a great challenge in sum rule method.

Following the diquark picture applied to weak hadron decays with sum rules [25], the diquark current with flavor (sq)

$$j_i(x) = \epsilon_{ijk} s_j^T(x) C O q_k(x) \tag{6}$$

was employed and an updated analysis was performed in a recent attempt [22]. The most "suitable" masses of diquark m_{qq} and m_{sq} were obtained: $m_{qq} \sim 400$ MeV and $m_{sq} \sim 460$ MeV with $s_0 = 1.2$ GeV^2. The mass scale of diquark is the same as that of the constituent quark. The results obtained here are consistent with the fit of Maiani's [23].

Once the masses determined by sum rule are taken as the constituent diquark masses, masses of the $L = 0$ and the $L = 1$ excited tetraquark state are obtained as the method of Maiani's [23]

$$M \approx 2m_{[qq]} - 3(\kappa_{qq})_{\bar{3}}, \quad M \approx 2m_{[qq]} - 3(\kappa_{qq})_{\bar{3}} + B'_q \frac{L(L+1)}{2}.$$

The obtained masses of some four-quark states are listed in tab.1. Tetraquark states consisting of bad diquark have the same mass scale [23]. It is easy to find the explicit flavor dependence of masses.

4 Exotica possibility of the new observations by BES

Some new observations were reported by BES through its 58 million events sample of J/Ψ decays.

$p\bar{p}$ enhancement was observed by BES [26] in the radiative decay $J/\Psi \to \gamma p\bar{p}$ with $M = 1859^{+3}_{-10}(stat)^{+5}_{-25}(sys)$ (below $2m_p$) and $\Gamma < 30$ MeV if interpreted as a single 0^{-+} resonance. It was observed also by Belle [31] and BaBar [32] collaborations in other channels. Its quantum number assignment J^{PC} is consistent with either 0^{-+} or 0^{++}. This enhancement was once interpreted as final state interaction effect, baryonium or threshold cusp.

$X(1835)$ was observed by BES [27] in the decay $J/\Psi \to \gamma\pi^+\pi^-\eta'$ with $M = 1833.7 \pm 6.1(stat) \pm 2.7(syst)$ MeV and $\Gamma = 67.7 \pm 20.3 \pm 7.7$ MeV. It is consistent with expectations for the state that produces the strong $p\bar{p}$ mass threshold enhancement. It was once interpreted as 0^{-+} glueball or baryonium.

$X(1812)$ was observed by BES [28] in the doubly OZI-suppressed decay $J/\Psi \to \gamma\omega\phi$ with $M = 1812^{+19}_{-26}(stat) \pm 18(syst)$ MeV, $\Gamma = 105 \pm 20 \pm 28$ MeV. It favors $J^P = 0^+$. It was interpreted as rescatterings effect, four-quark state, glueball or hybrid.

$X(1576)$ was observed by BES [29] in the decay $J/\Psi \to K^+K^-\pi^0$ with pole position $1576^{+49}_{-55}(stat)^{+98}_{-91}(syst)$ MeV-$i(409^{+11}_{-12}(stat)^{+32}_{-67})$ MeV. This broad peak is believed to have $J^{PC} = 1^{--}$. It was interpreted as final state interaction effect or tetraquark state.

Exotica was often invoked to explain the special features of newly observed states. Based on previous analysis, the glueball and tetraquark possibility of these observations is examined.

In QCD sum rule approach, the two glueball candidates with lower mass are 0^{++} and 0^{-+} glueball. Therefore, $X(1835)$ and $X(1812)$ may be a 0^{++} glueball, but they are unlike to be the pure 0^{-+} glueball.

0^{++} and 0^{-+} tetraquark states have the same mass scale, and they have lower masses compared with the new observations by BES. It is hard to explain these observations as 0^{++} or 0^{-+} tetraquark state. If $X(1576)$ is confirmed to have 1^{--}, it may be the first orbital excited 1^{--} tetraquark state (orbital excitation of $a_0(980)$ or $f_0(980)$) with a very large excited energy ~ 596 MeV.

5 Conclusions and discussions

Different interpolating currents have been employed to study exotic states, but the structure of interpolating currents has no direct correspondence to the constituent structure of hadrons. The study of exotica with sum rule requires more exploration.

Masses of 0^{++}, 0^{-+} glueballs and some tetraquark states were determined. Through these studies, the new observations by BES are unlike to be the pure 0^{-+} pseuso-scalar glueball, they are unlikely to be the light tetraquark states either except that $X(1576)$ may be an exotic first orbital excited $(sq)(\bar{s}\bar{q})$ tetraquark state.

6 Acknowledgements

This work is supported in part by NSFC under the grant: 10775093. The author thanks all the collaborators and is grateful to the organizing committee for partial financial support.

References

1. M.A. Shifman, A.I. Vainshtein and V.I. Zakharov, Nucl. Phys. **B147**, 385 (1979).

2. H. Fritzsch and M. Gell-Mann, 16th Int.Conf. High-Energy Phys., Chicago, Vol. 2, 135 (1972).

3. V.A. Novikov, *et al.*, Nucl. Phys. **B165**, 67 (1980).

4. S. Narison, Nucl. Phys. **B509**, 312 (1998).

5. Tao Huang, *et al.*, Phys. Rev. **D59**, 034026 (1999).

6. D. Harnett and Tom Steele, Nucl. Phys. **A695**, 205 (2001).

7. H. Forkel, Phys. Rev. **D71**, 054008 (2005).

8. V.A. Novikov, *et al.*, Nucl. Phys. **B191**, 301 (1981)

9. Ailin Zhang and Tom Steele, Nucl. Phys. **A728**, 165 (2003).

10. J.I. Latorre, S. Narison and S. Paban, Phys. Lett. **B191**, 437 (1987).

11. Gang Hao, Cong-Feng Qiao and Ailin Zhang, Phys. Lett. **B642**, 53 (2006).

12. R.L. Jaffe, Phys. Rev. **D15**, 267 (1977); **D15**, 281 (1977).

13. Hong-Mo Chan and H. Högaasen, Phys. Lett. **B72**, 121 (1977).

14. J. Weinstein and N. Isgur, Phys. Rev. Lett, **48**, 659; Phys.Rev. **D27**, 588 (1983); Phys.Rev. **D41**, 2236 (1990);
    N.A. Törnqvist, Phys. Rev. Lett, **67**, 556 (1991);
    L.Y. Glozman and D. O. Riska, Phys. Rept, **268**, 263 (1996).

15. D. Black, A.H. Fariborz, J. Schechter, Phys. Rev. **D59**, 074026 (1999).

16. D. Ebert, R.N. Faustov, V.O. Galkin, Phys. Lett. **B634**, 214 (2006).

17. Ailin Zhang, Phys. Rev. **D61**, 114021 (2000).

18. Thomas Schafer, Phys. Rev. **D68**, 114017 (2003).

19. M.E. Bracco, A. Lozea, R.D. Matheus, *et al.*, Phys. Lett. **B624**, 217 (2005).

20. Hungchong Kim and Yongseok Oh, Phys. Rev. **D72**, 074012 (2005).

21. Hua-Xing Chen, *et al.*, Phys. Rev. **D74** , 054001 (2006).

22. Ailin Zhang, Tao Huang and Tom. Steele, Phys. Rev. **D76** , 036004 (2007)

23. N.N. Achasov, *et al.*, Phys. Lett. **B108**, 134 (1982);
N.N. Achasov and V.N. Ivanchenko, Nucl. Phys. **B315**, 465 (1989);
J.R. Pelaez, Phys. Rev. Lett. **92**, 102001 (2004);
L. Maiani, F. Piccinini, A.D. Polosa and V. Riquer, Phys. Rev. Lett. **19**, 212002 (2004); Phys. Rev. **D71**, 014028 (2005);
I.V. Anikin, B. Pire and O.V. Teryaev, Phys. Lett. **B626**, 86 (2005);
D.Melikhov and B. Stech, Phys. Rev. **D74**, 034022.

24. S. Godfrey and J. Napolitano, Rev. Mod. Phys. **71**, 1411 (1999);
C. Amsler and N.A. Törnqvist, Phys. Rept. **389**, 61 (2004);
D. V. Bugg, Phys. Rept. **397**, 257 (2004);
R.L. Jaffe, Phys. Rept. **409**, 1 (2005);
E. Klempt, A. Zaitsev, Phys. Rept. **454**, 1 (2007).

25. H.G. Dosch, M. Jamin and B. Stech, Z. Phys. **C42**, 167 (1989); M. Jamin and M. Neubert, Phys. Lett. **B238**, 387 (1990)

26. J.Z.Bai, *et al.* (BES Collaboration), Phys. Rev. Lett. **91**, 022001 (2003)).

27. M. Ablikim, *et al.* (BES Collaboration), Phys. Rev. Lett. **95**, 262001 (2005).

28. M. Ablikim, *et al.* (BES Collaboration), Phys. Rev. Lett. **95**, 262001 (2005).

29. M. Ablikim, *et al.* (BES Collaboration), Phys. Rev. Lett. **96**, 162002 (2006).

30. M. Ablikim, *et al.* (BES Collaboration), Phys. Rev. Lett. **97**, 142002 (2006).

31. M.-Z. Wang *et al.* (Belle Collaboration), Phys. Lett. **B617**: 141 (2005).

32. B. Aubert *et al.* (BaBar Collaboration), Phys. Rev. **D74**: 051101 (2006).